

# Supersonic Particle Deposition for Repair and Corrosion Protection of Mg Gearboxes

**ASETSDefense Work Shop**  
**Sept. 2, 2009**

**Brian M. Gabriel, Phillip F.  
Leyman, Dennis J. Helfritch,  
and Victor K. Champagne\***  
**ARL Center for Cold Spray**

**Brian M. Gabriel**  
**Army Research Laboratory**  
**RDRL-WMM-C**  
**Building 4600, Deer Creek Loop**  
**APG, MD 21005**  
**Phone: (410) 306-2719**  
**Fax: (410) 306-0829**  
**brian.m.gabriel@arl.army.mil**

***\*Program Manager and POC for  
ARL Center for Cold Spray***



**Before**



**After**

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# Core Team Members



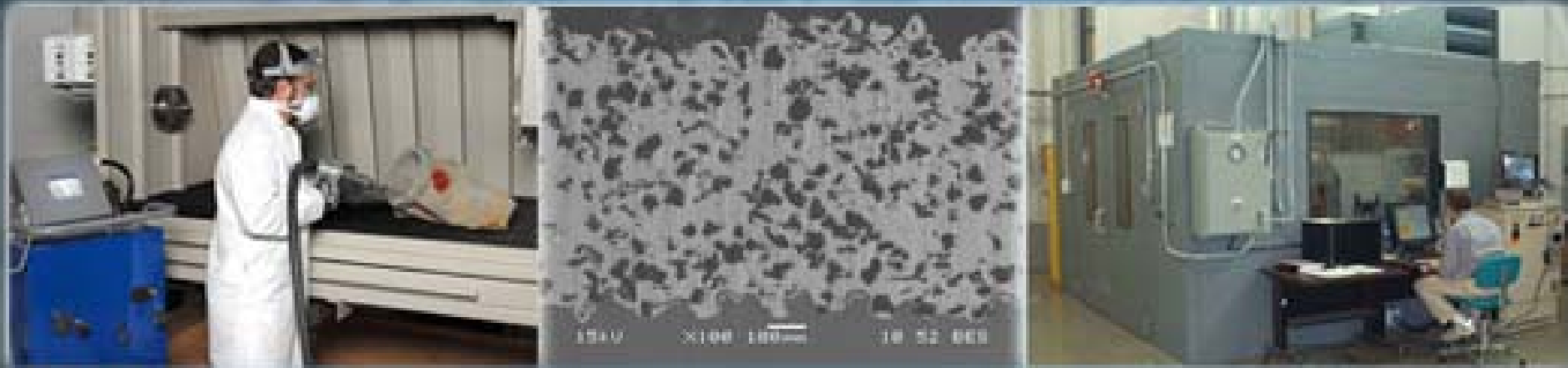
- **Victor Champagne- Program Manager – Cold Spray Center Primary Contact**, Army Research Laboratory, Aberdeen Proving Ground, MD, 410-306-0822, [vchampag@arl.army.mil](mailto:vchampag@arl.army.mil)
- **Robert Kestler**, NADEP-CP, Cherry Point, NC 252-464-9888  
[robert.kestler@navy.mil](mailto:robert.kestler@navy.mil)
- **Robert Guillemette**, Sikorsky Aircraft, Stratford, CT 203-386-7559  
[rguillemette@sikorsky.com](mailto:rguillemette@sikorsky.com)
- **George Liu**, Army Aviation Missile Command, Huntsville, AL, 256-313-8762, [george.g.liu@us.army.mil](mailto:george.g.liu@us.army.mil)
- **Timothy J. Eden**, Applied Research Laboratory, The Pennsylvania State University, State College, PA, 814-865-5880, [tje1@email.psu.edu](mailto:tje1@email.psu.edu)
- **Darren Gerrard**, DSTO, Australia 61-396-267957  
[darren.gerrard@dsto.defence.gov.au](mailto:darren.gerrard@dsto.defence.gov.au)
- **Stacey Luker**, JSF ESOH, Cherry Point, NC 252-444-2034  
[stacey.luker@wylelabs.com](mailto:stacey.luker@wylelabs.com)
- **Keith Legg**, Rowan Technology Group, Libertyville, IL 847-680-9420  
[klegg@rowantechnology.com](mailto:klegg@rowantechnology.com)





- Demonstrate and qualify SPD aluminum alloy coatings as a cost-effective, ESOH-acceptable technology to provide surface protection and a repair/rebuild methodology for Mg alloy components on Army and Navy helicopters and advanced fixed-wing aircraft such as the Joint Strike Fighter

## ARL Center for Cold Spray

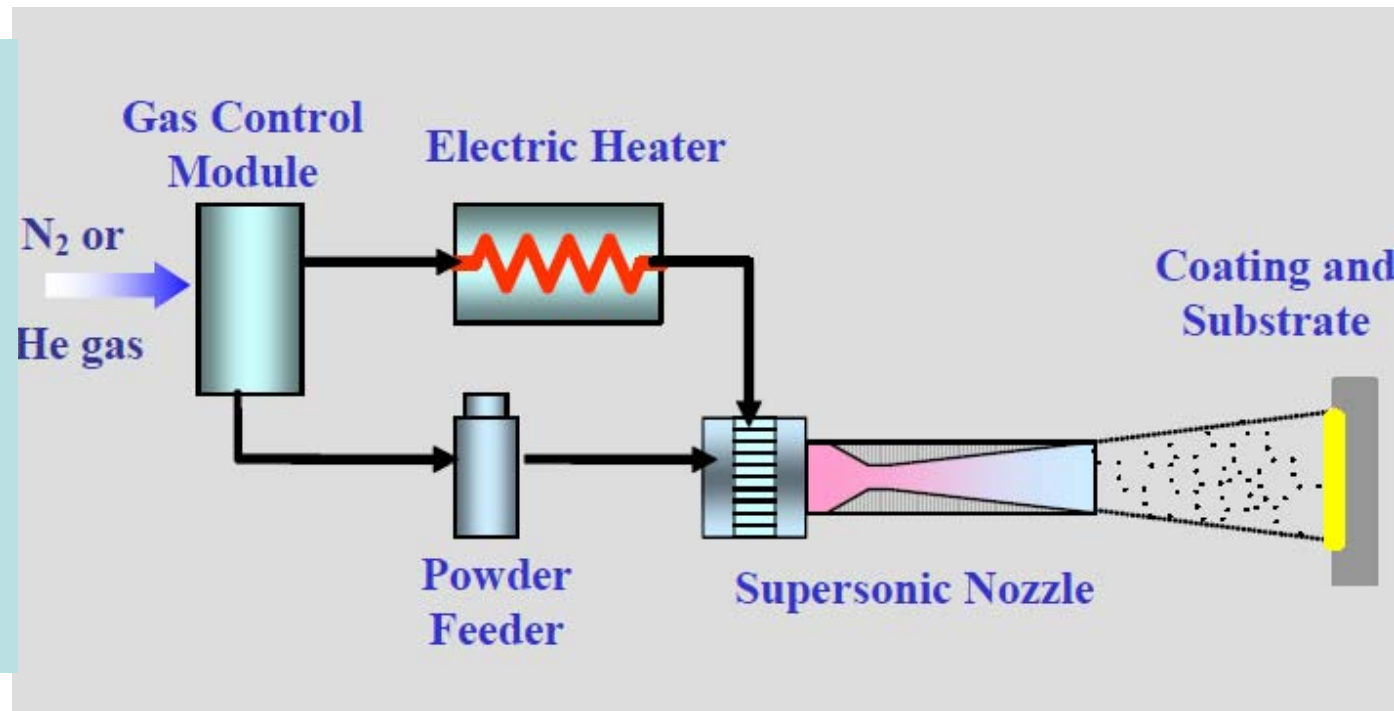


*Enhancing the Performance of Materials and Components*

## Cold Spray/SPD Process

Cold spray, involves the introduction of a heated high-pressure gas such as He or N<sub>2</sub> together with 1 to 50 µm diameter particles of a metal, ceramic and/or polymer into a gun fitted with a De Laval rocket nozzle designed such that the particles exit at supersonic velocities ranging from 400 to 1500 meters-per-second and consolidate upon impacting a suitable surface to form a coating or free-standing structure.

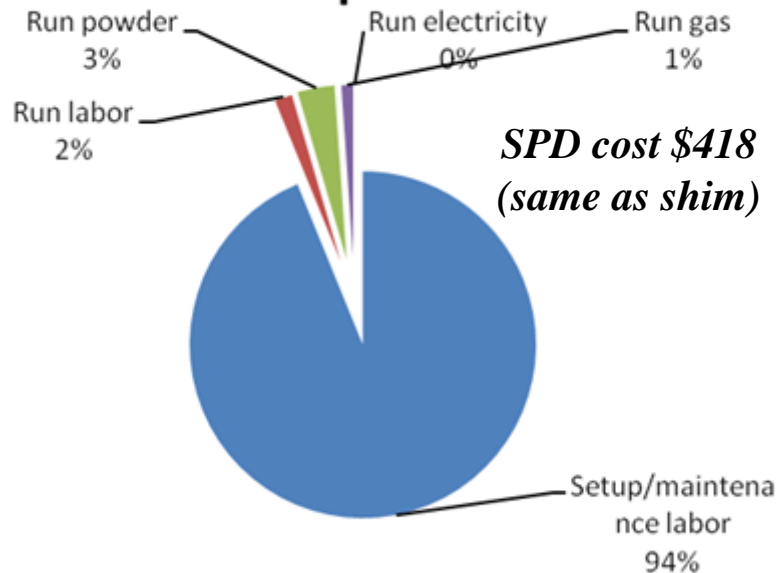
- *Gas temperature range from R.T. to 800°C*
- *No melting of particles*
- *Negligible oxidation*
- *No decomposition or phase changes of deposited particles*



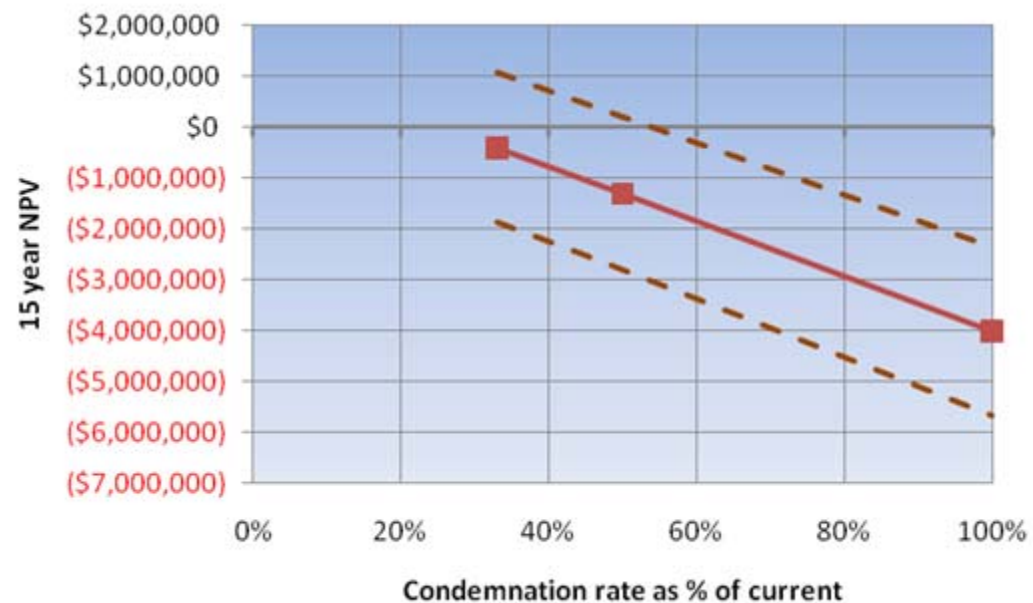


- ***SPD has little or no impact on repair cost***
- ***Most of cost is setup – actual process cost is small (same as glue shims)***
- ***Payback of capital and implementation cost is 15 yrs with CH-53 only***
  - ***Depends on performance – reduced repair or condemnation***
  - ***Faster payback over all FRC workload***

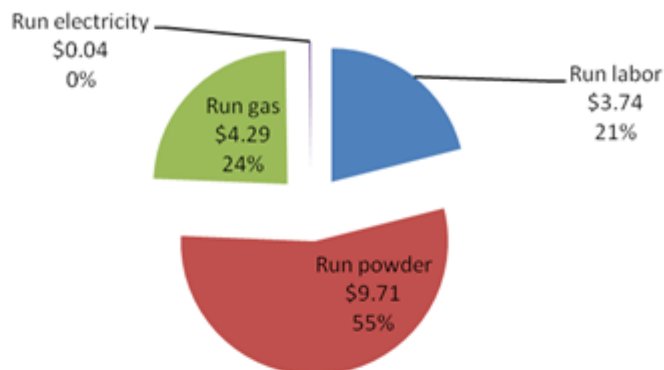
## CH-53 Foot repair - total cost



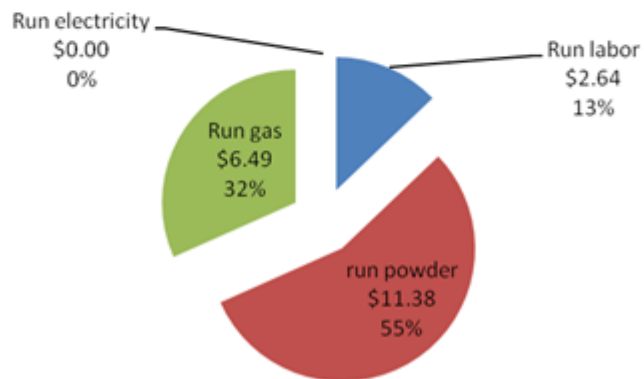
## CH-53 only $\pm 2\sigma$



## SPD UH-60 sump flange - run cost



## HVOF UH-60 sump flange - run cost



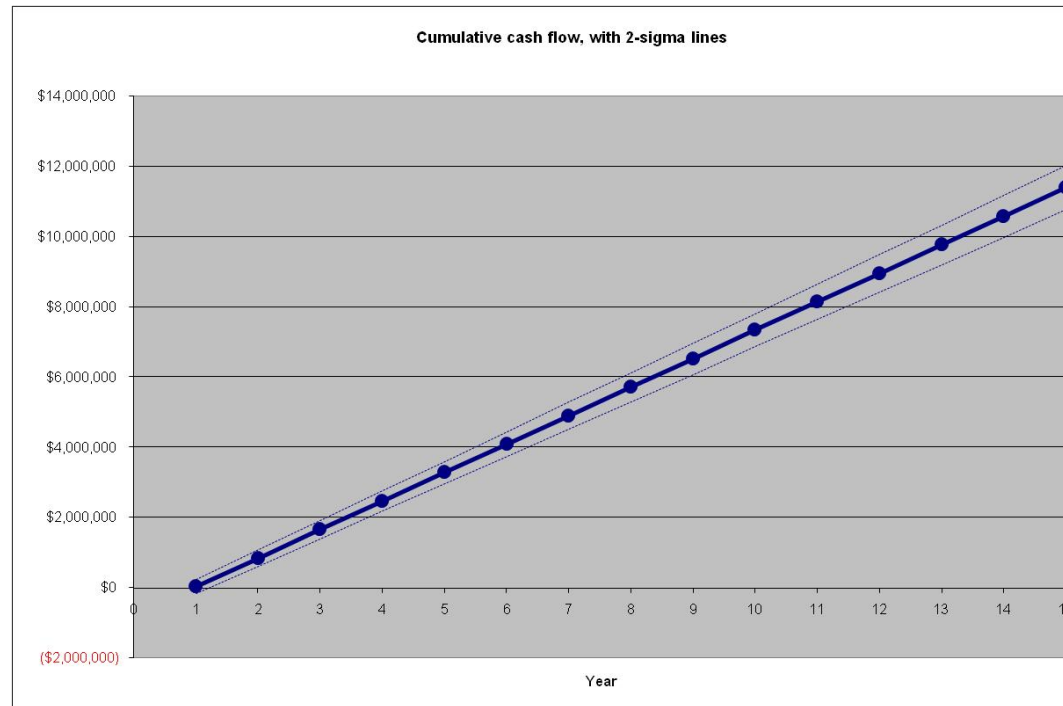
	SPD	HVOF
Setup/maintenance labor	\$392.50	\$392.50
Run labor	\$3.74	\$2.64
Run powder	\$9.71	\$11.38
Run gas	\$4.29	\$6.49
Run electricity	\$0.04	\$0.00
Total cost	\$410.28	\$413.01
Run cost	\$17.78	\$20.51

***No cost impact (both processes vendor-supplied)***





- **Problem is that HVOF does not really work**
  - **Therefore SPD saves condemnation**
- **85 gearboxes/year**
  - **\$11k ea to replace**
  - **\$1k ea to repair**
- **Cost analysis includes equipment installation and adoption cost**
- **Larger cost savings with more expensive gearbox housings**



	-2 sigma	Value	+2 sigma
15 yr NPV	\$8,682,158	\$9,229,033	\$9,775,908
IRR	145%	111%	91%
ROI	82%	111%	140%
Payback period	1.2	0.0	0.0

## ***UH-60 Sump Assembly Main Module-Main Gearbox Repair***



***Substrates:  
ZE41A & AZ91C  
Magnesium  
Coating Material:  
CP-Aluminum  
and/or 6061 Al***

***Part Numbers:  
70351-48141-041  
70351-08141-047***

- ***Cost of new component \$11,000.00 DLA (Defense Logistics Agency)***
- ***85 sumps need repair per year based on a Sikorsky study over the last 3 years***
- ***Total Replacement Cost Savings estimated to be **\$935,000.00/year*****

## Substrate Materials

Material	Heat Treat (tens. strength)	Notes
AZ91C-T6	34 ksi	Legacy systems
ZE41A-T5	29 ksi	Legacy systems
EV31-T6	36 ksi	New CH-53, AAV

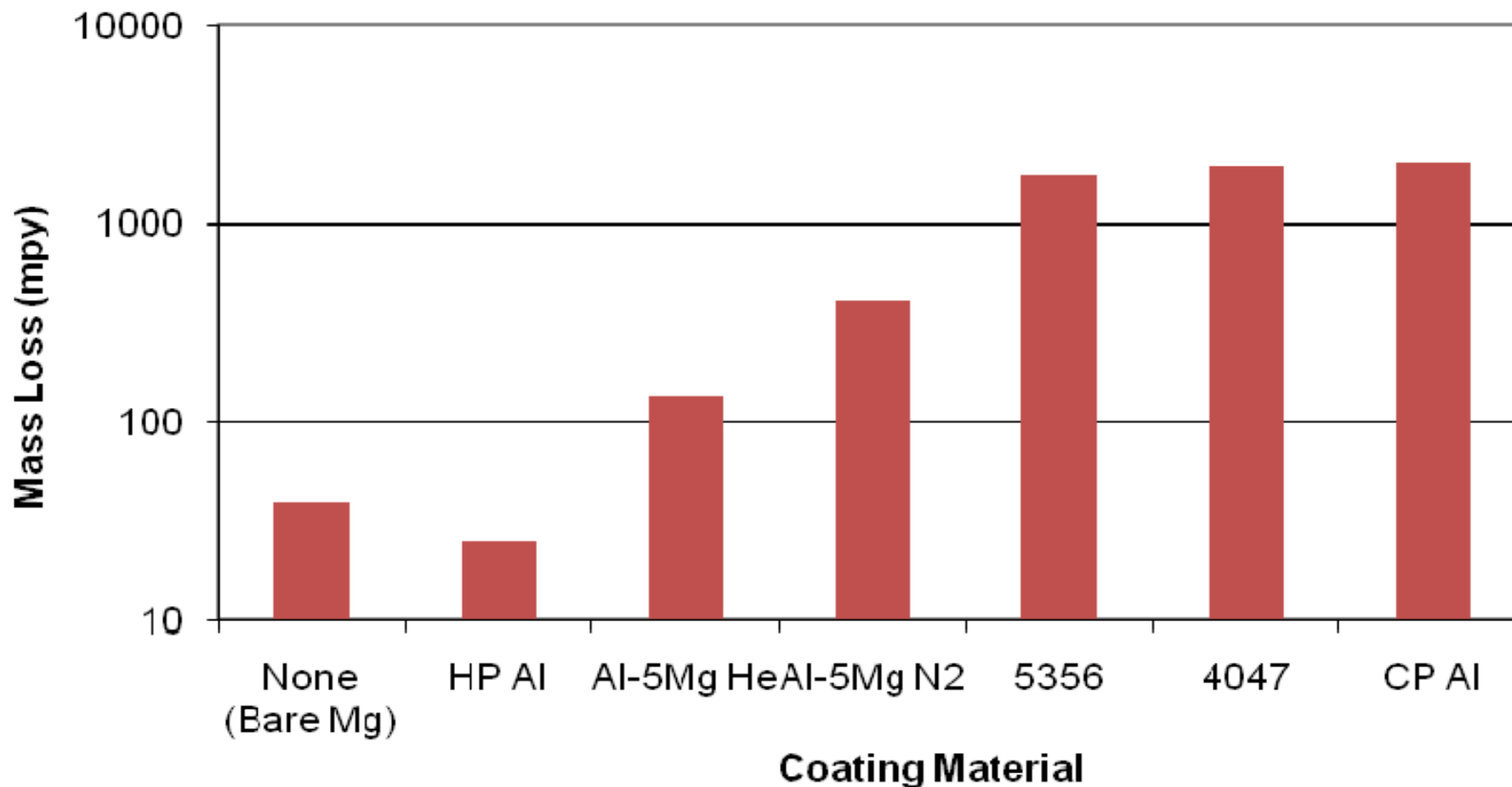


**RR Moore with 6061 SPD Coating**

## Candidate Coating Materials

- Commercially Pure Al- Hardness similar to ZE41A (60 to 70 VHN), Good general corrosion resistance. Candidate for non-structural coatings
- High Purity Al- Best Galvanic compatibility with Mg alloys but at a cost of lower hardness (50 VHN)
- 6061 aluminum alloy: 90 to 110 VHN, good general corrosion resistance, future candidate for more structural or load bearing coatings.

## Galvanic Corrosion - Al-Mg Couple



*Cathode slightly larger than anode*



## Full JTP Qualification Plan

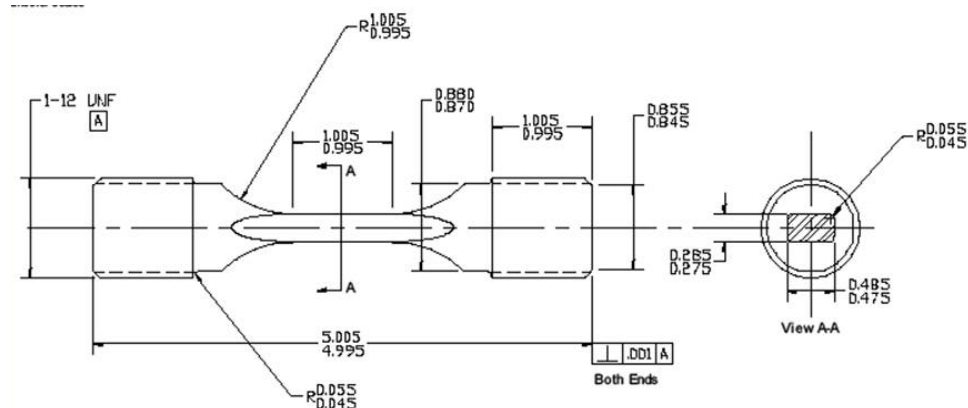
### Mechanical Tests

- Adhesion Tensile Bond Test (ASTM C633)
- Almen Strips
- Flat Tensile Specimens
- R.R. Moore RB Fatigue
  - surface finished 125RA
- Fretting Fatigue – UTRC
- Impact - ASTM D5420
- Hardness
- Porosity
- ROSAN Insert Test
- Triple Lug Shear

1. 6061 Aluminum Alloy (He carrier gas)
2. HP-Al Bond Coat/CP-Al (N<sub>2</sub> carrier gas)

### Corrosion Tests

- Un-scribed ASTM B117
- Scribed ASTM B117
- GM9540 Scribed
- Galvanic Corrosion (G71)
- Crevice Corrosion (G78)
- Beach Corrosion
- G85 Annex 4-SO<sub>2</sub>



*UTRC Fretting Fatigue Specimen*

**Substrates: ZE41A & AZ91C Magnesium Alloys**

**Coating Material:**

**1.1. 6061 Aluminum Alloy (He carrier gas)**

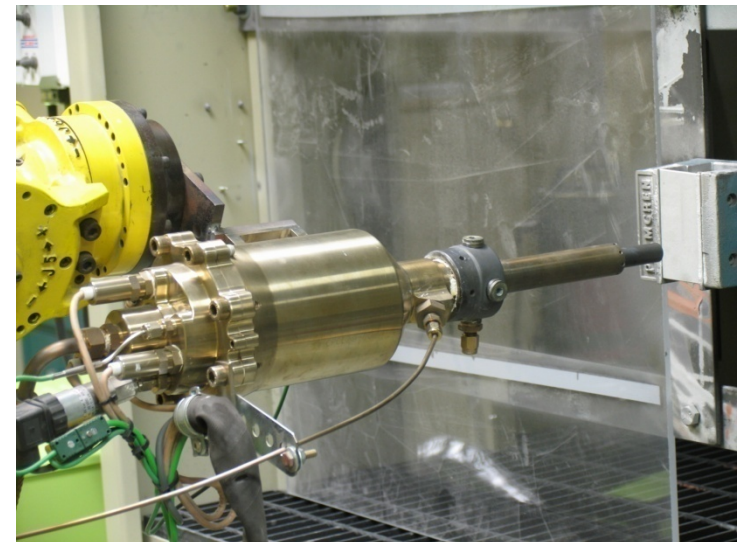
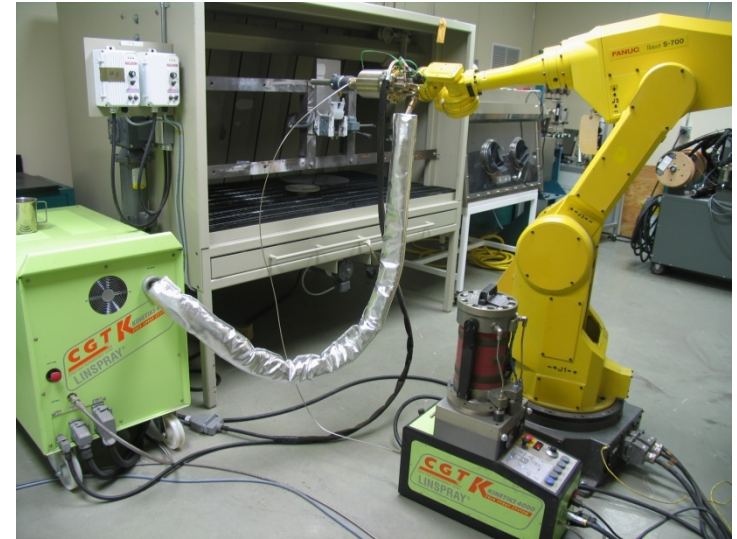
**2.HP-Al Bond Coat/CP-Al (N<sub>2</sub> carrier gas)**

- Porosity < 1%
- Almen Strips
- Adhesion Tensile Bond Strength Test
- Unscribed ASTM B117 Salt Spray Test
- Scribed ASTM B117 Salt Spray Test
- G85 SO<sub>2</sub>
- Beach Corrosion
- Hardness –(Pre/Post 385F-6hrs)
- Machining Evaluation  
Coupons(1/2 coated) & 1/2" diameter rods (2" of 6" length)



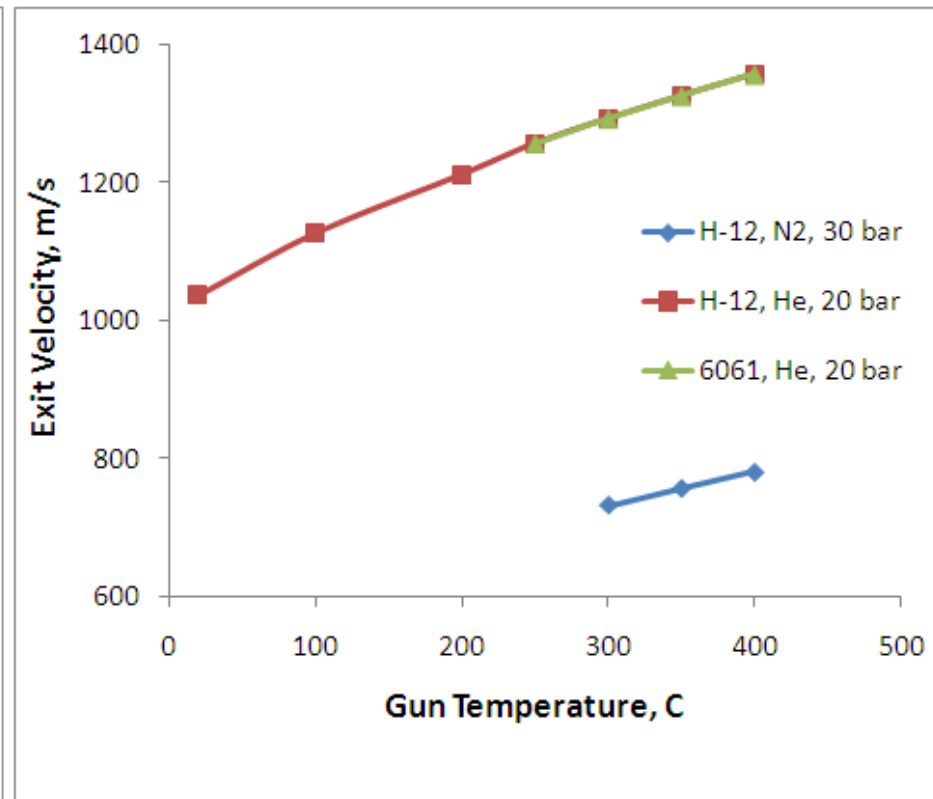
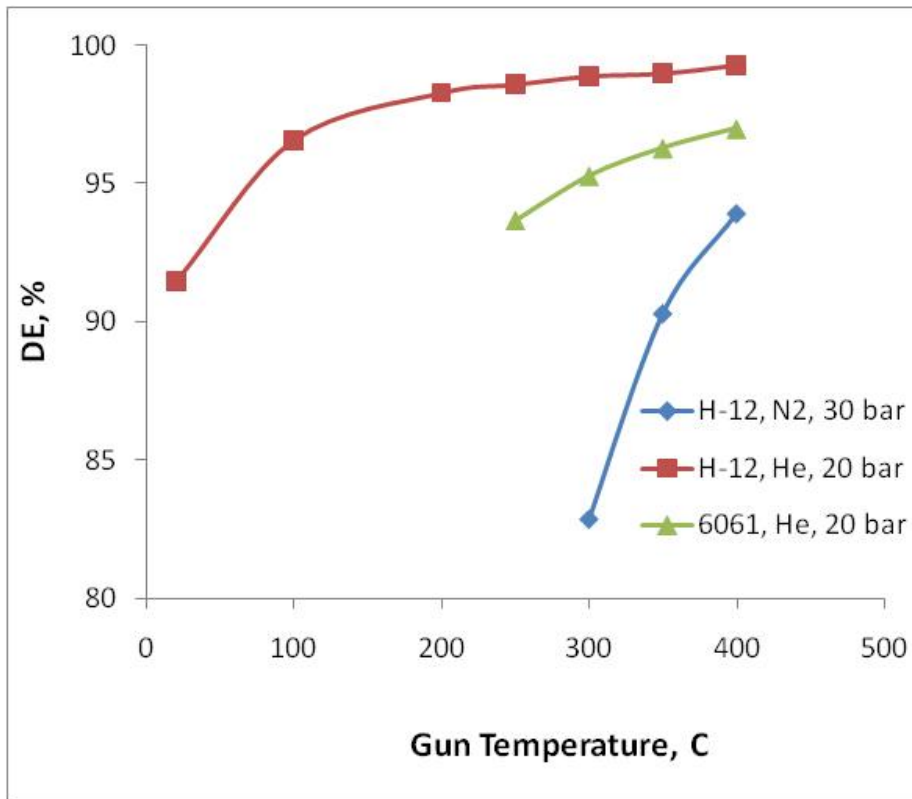
- Over 550 Coated Samples (JTP and Sump Qualification)
  - 6061 samples were started on July 25 and anticipated to be completed by September 1
  - HP-Al bond coat/CP-Al sprayed with N<sub>2</sub> should be completed by September 25
- Testing is being coordinated with Penn State, Pax River, Cherry Point, Westmoreland, L&M Machine Shop, TEC, and UTRC. December 2009 for most data!
- Demonstration at Cherry Point by the end of 2009
- Qualification of ASB and Demonstration at their site by the end of 2009
- Possibility that DSTO, Rosebank, and the Australian Navy might sign off on the process by the end of 2009

- 47 kW system Installed 6/2008 at APG (30 kW on floor and 17kW on gun)
- Only high pressure/high temperature C.S. system currently on the market
  - Temperatures up to 800°C (1472°F)
  - Pressures up to 40 bar (580 PSI)
- 17 kW system installation at NADEP-CP
  - Larger heat to be installed in late 2009
- Ktech System at ARL:
  - Temperature limited to 500°C
  - Pressures up to 35 bar (500 PSI)
  - 25 kW heater on floor
  - Heated powder gas feed

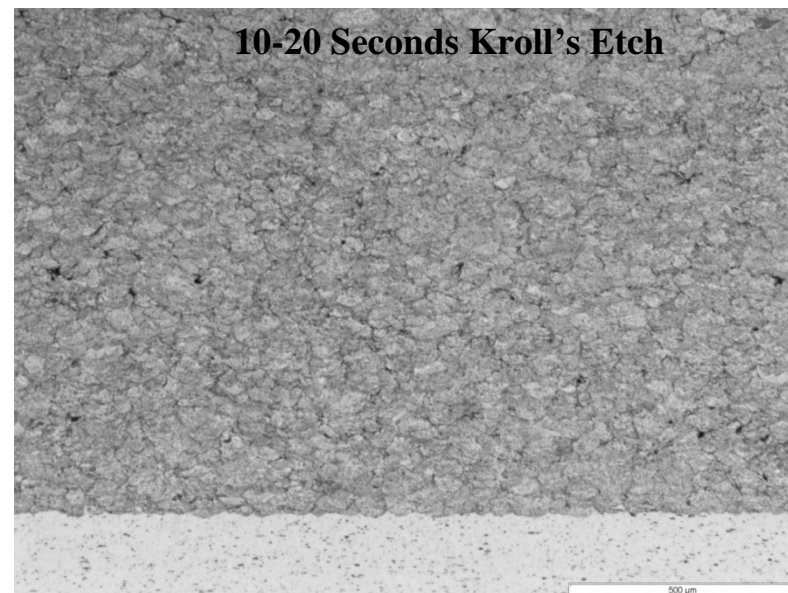
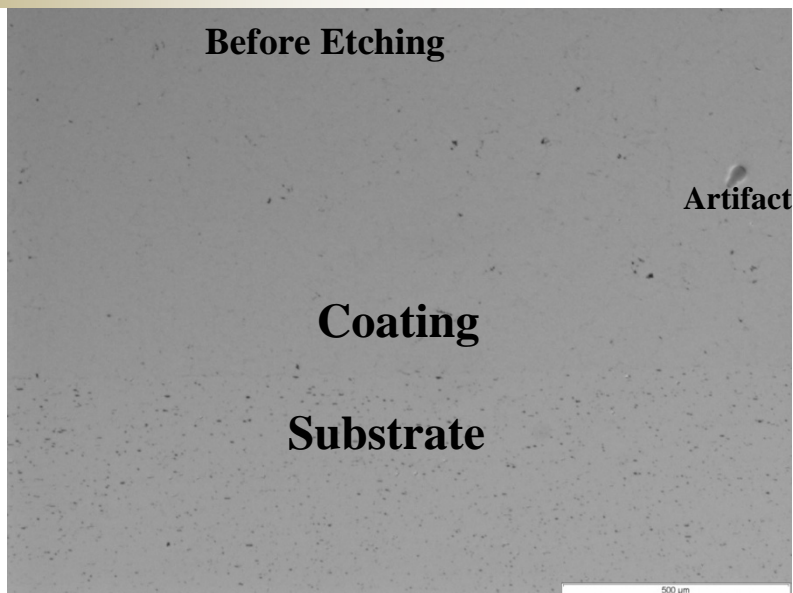




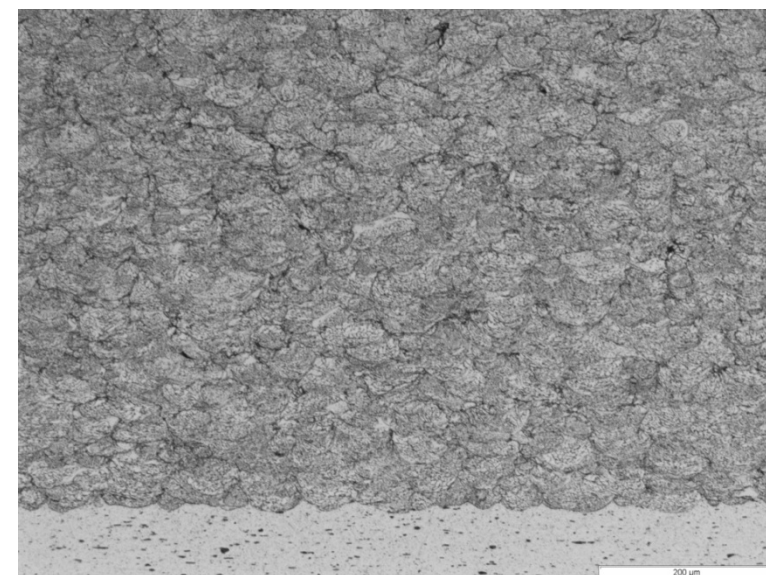
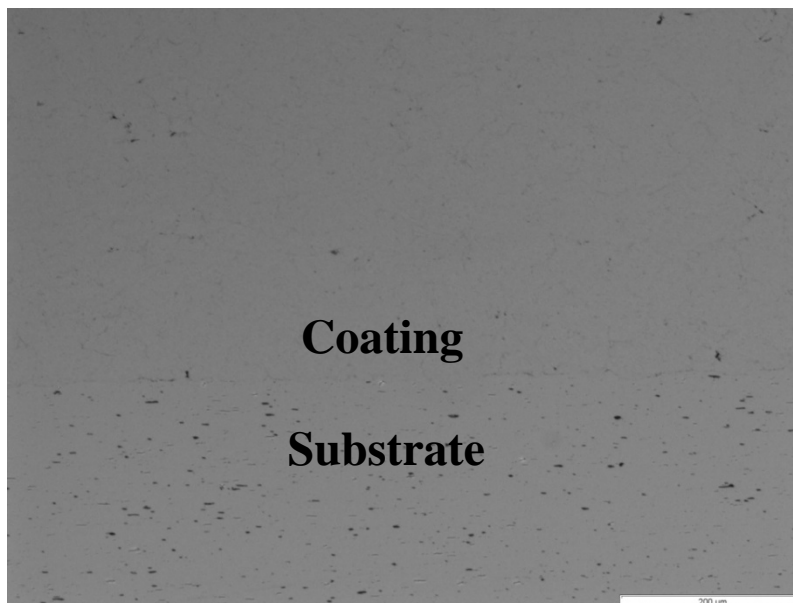
Modeled deposition efficiencies appear to be close to experimental values while the calculated velocities are well above the critical velocities for Al (~500 m/s)



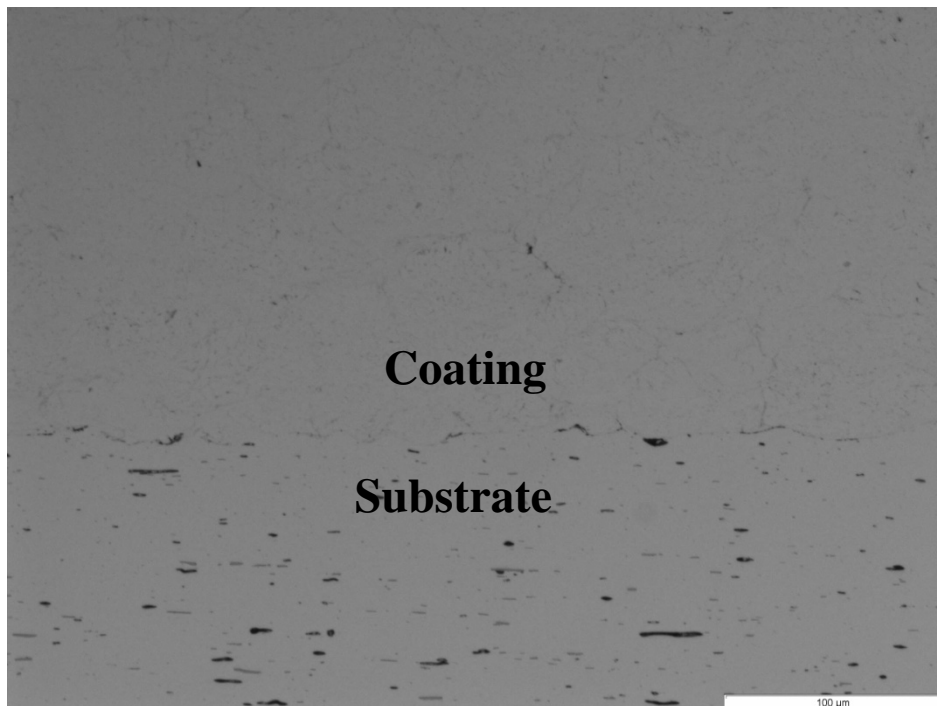
**50X**



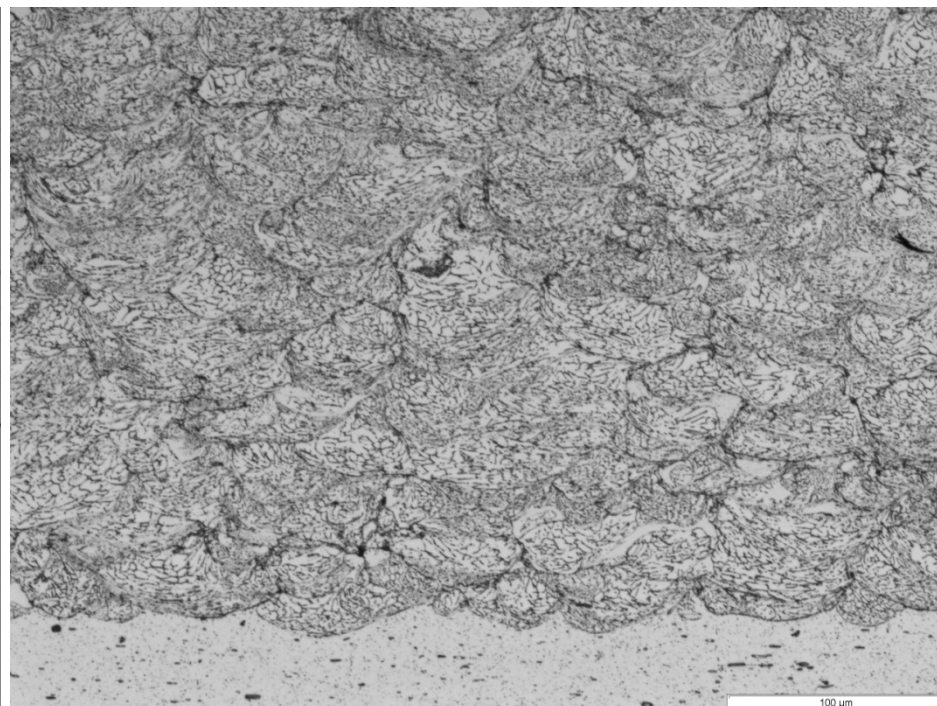
**100X**



**Before Etching**



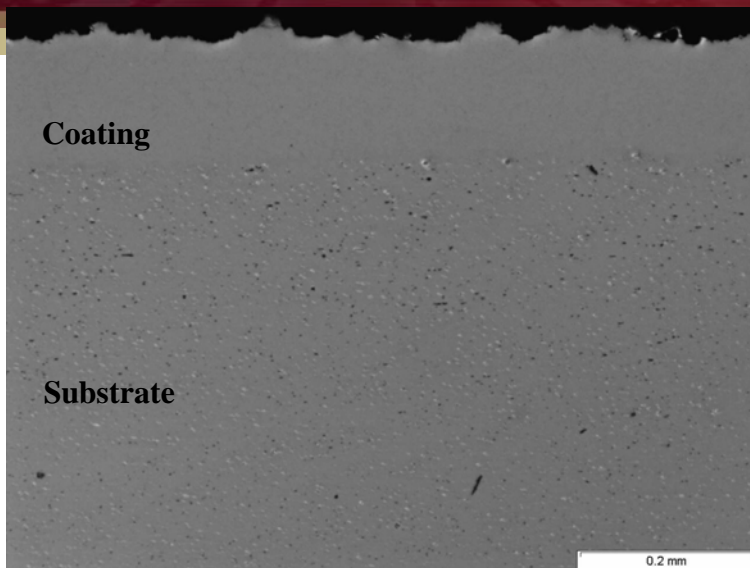
**10-20 Seconds Kroll's Etch**



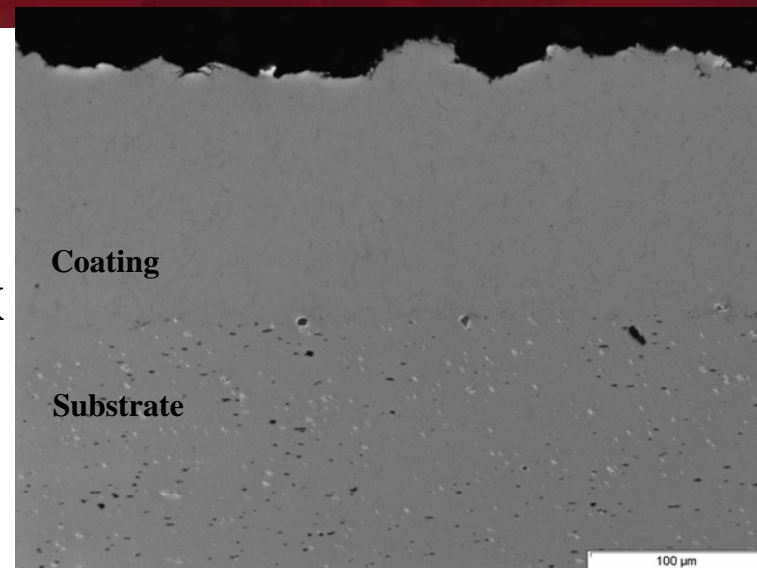
**200X**



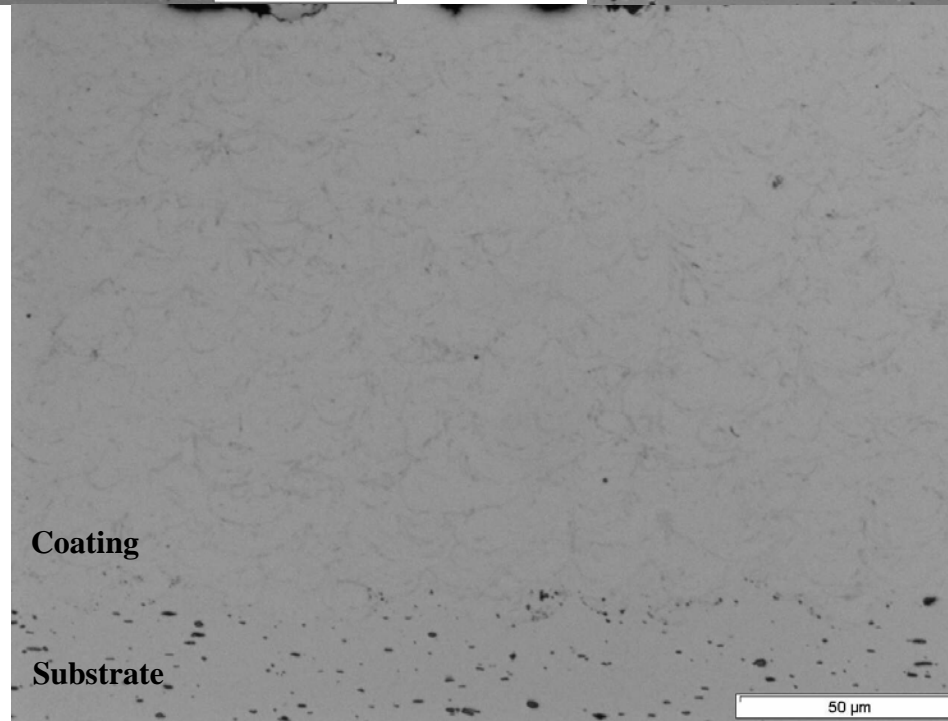
**50X**



**100X**



**200X**

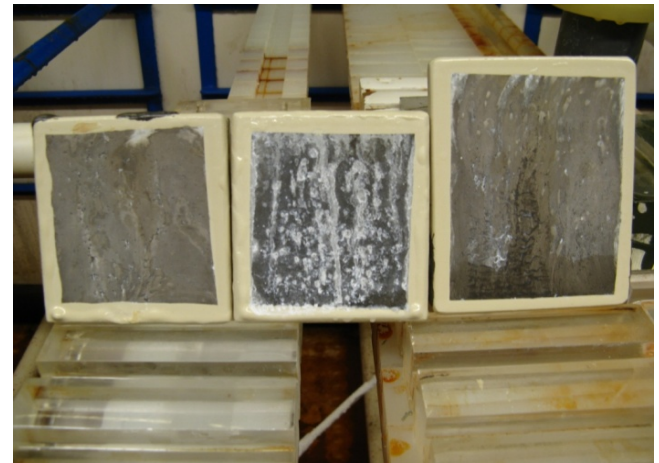




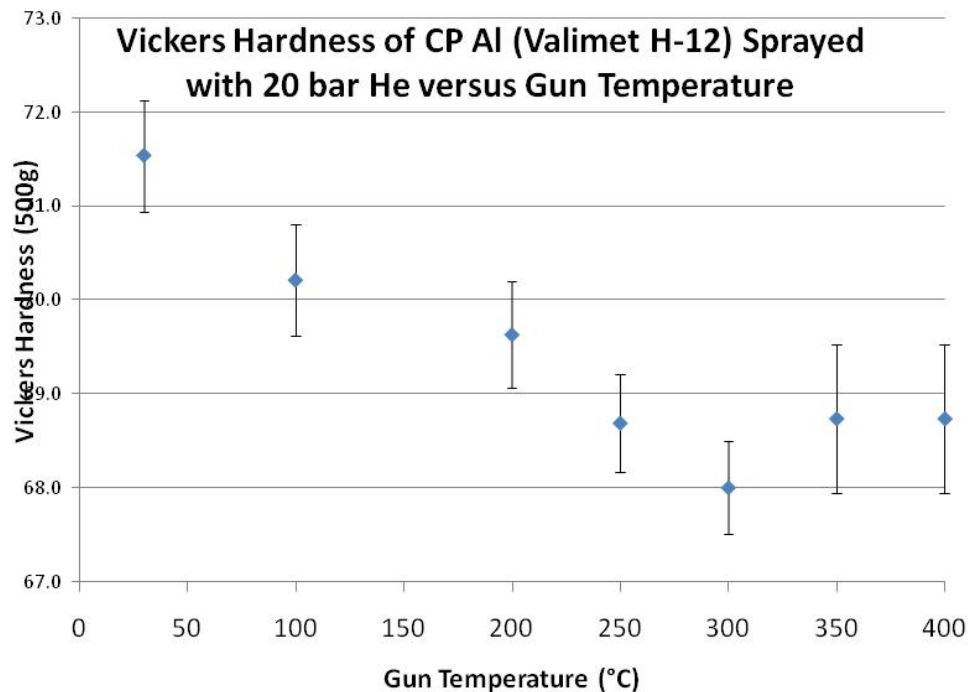
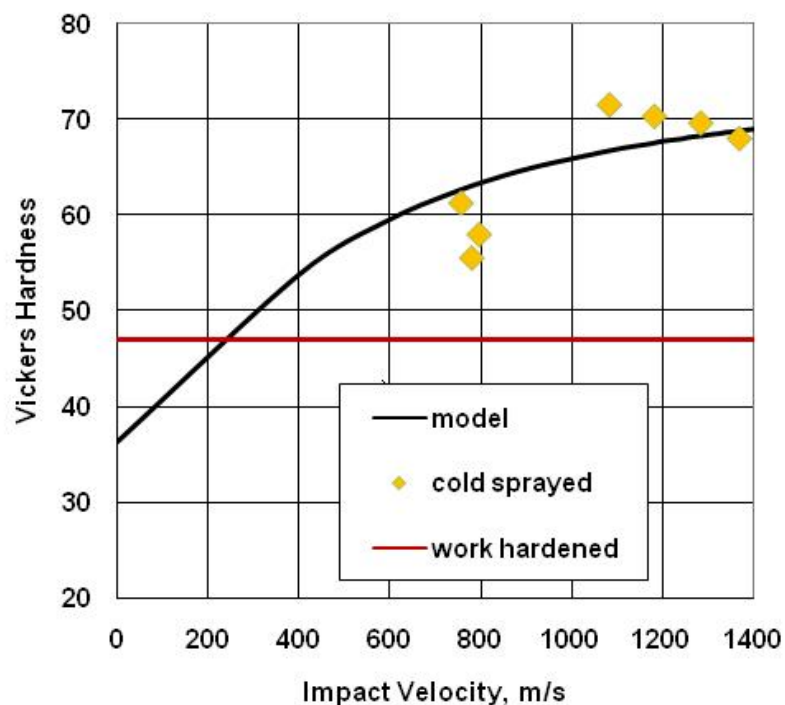
- Improved D.E. from 34% to over 60% as compared to the K-Tech
- Adhesion values similar to K-Tech (10 KSI for CP-Al)
- Coating Densities >98.5% Theoretical Density for CP-Al with N<sub>2</sub>  
>99.3% for 6061AA with He



**CP-Al Cold Spray Coatings entered Salt Fog on 3/4/09 ((~1/2 yr.)**



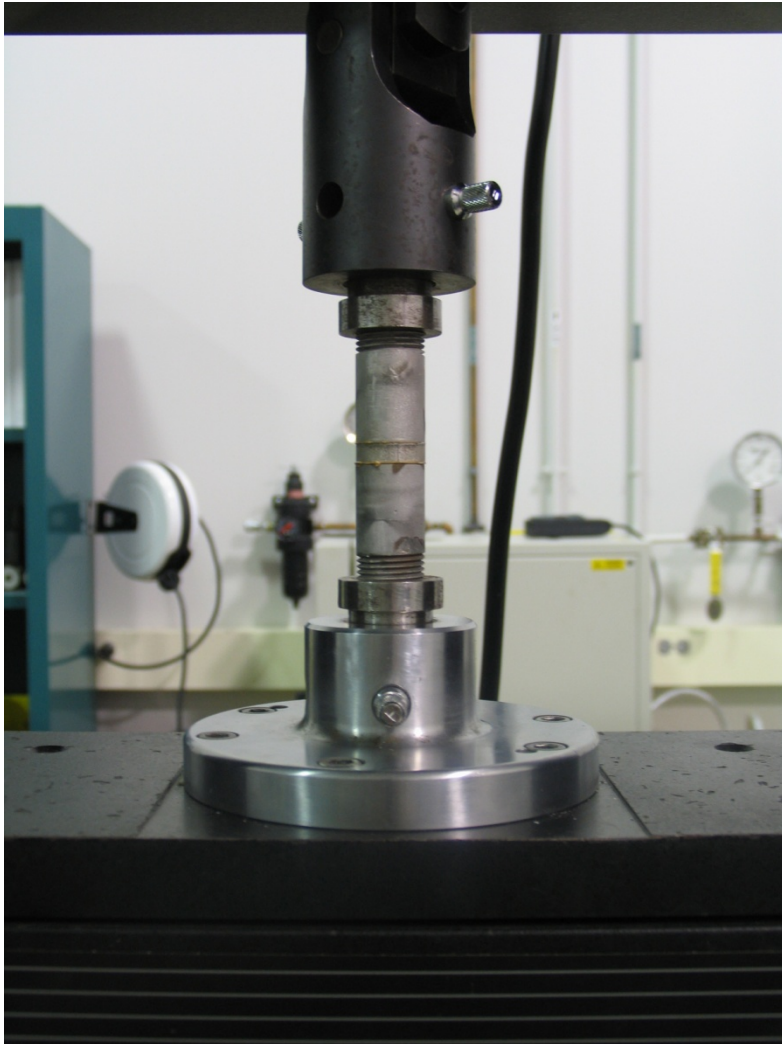
**6061 Cold Spray Coatings entered Salt Fog on 3/9/09 (~1/2 yr.)**



## 6061 Results:

**All Samples failed within the adhesive and not at the coating/substrate interface**

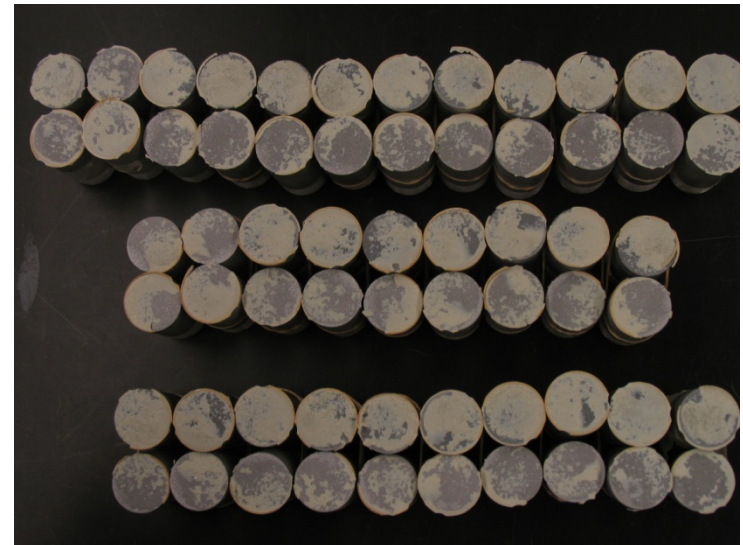
Alloy	Average (ksi)	Stdev (ksi)	95% Confidence (ksi)
ZE41A-T5	11.1	0.8	10.5, 11.6
AZ91C-T6	10.8	1.1	9.9, 11.6
EV31-T6	11.2	0.7	10.8, 11.7



**ZE41A-T5**

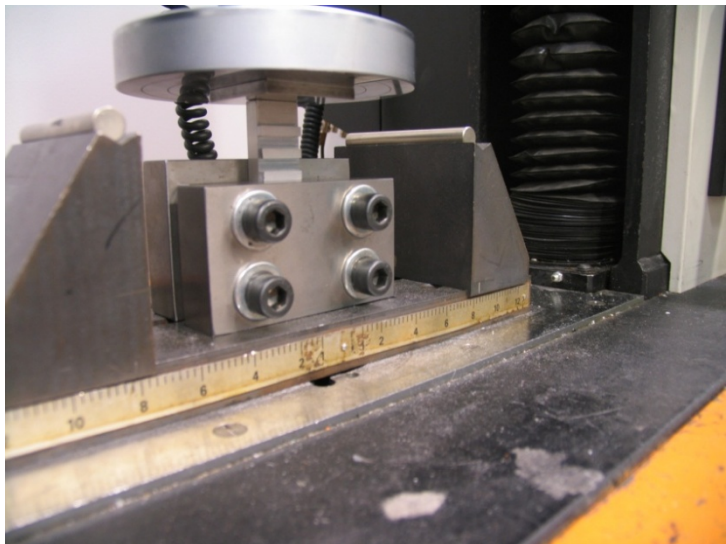
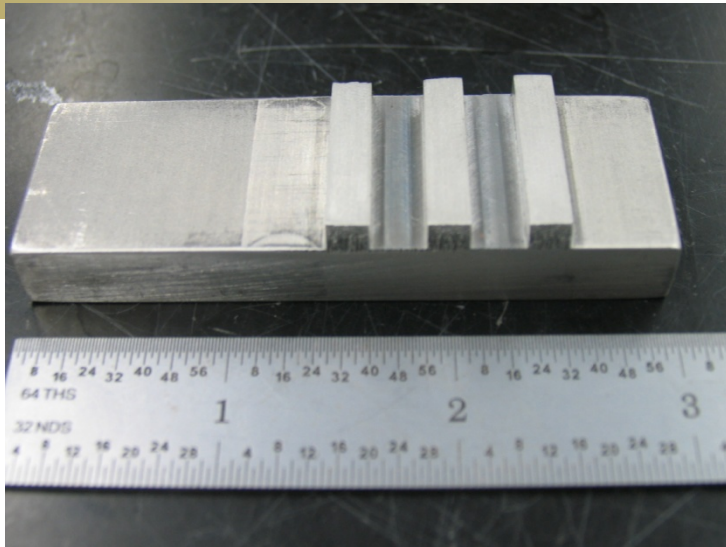
**AZ91C-T6**

**EV31-T6**



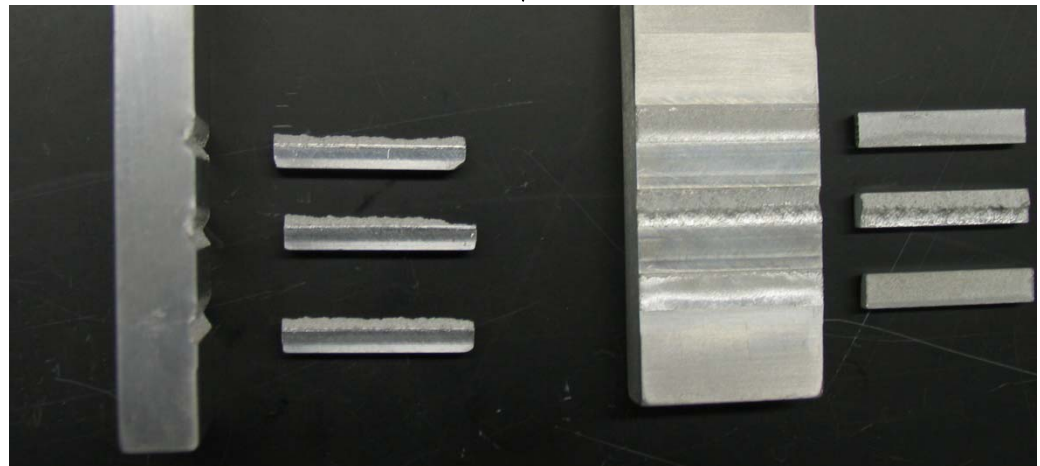
**CP-Al Preliminary ESTCP Data and DSTO Data show 10 ksi+**



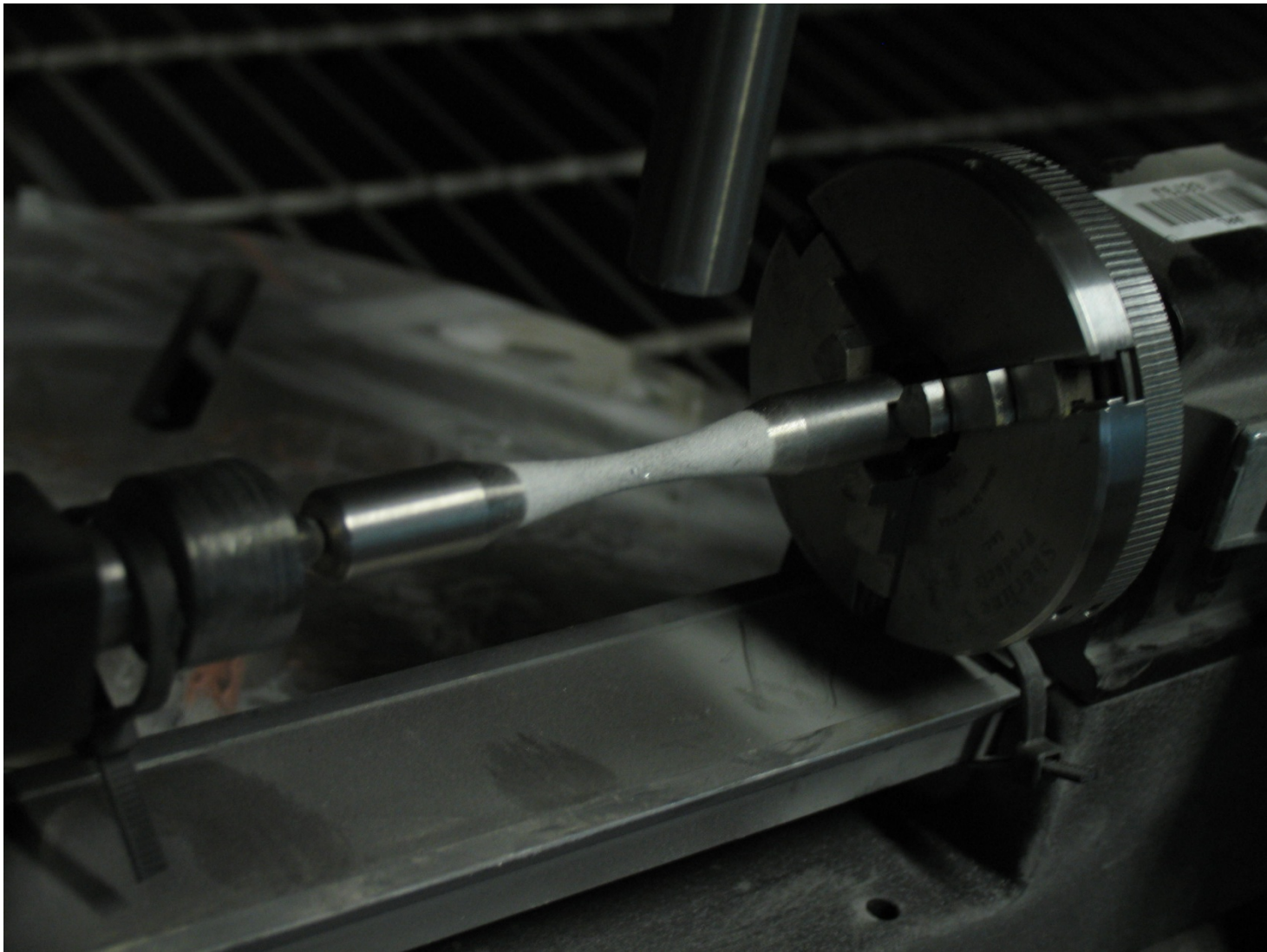


Alloy	Average (ksi)	Stdev (ksi)	95% Confidence (ksi)
ZE41A-T5	20.4	0.8	19.9, 20.8
AZ91C-T6	19.0	2.5	17.5, 20.5
EV31-T6	22.1	2.8	20.5, 23.7

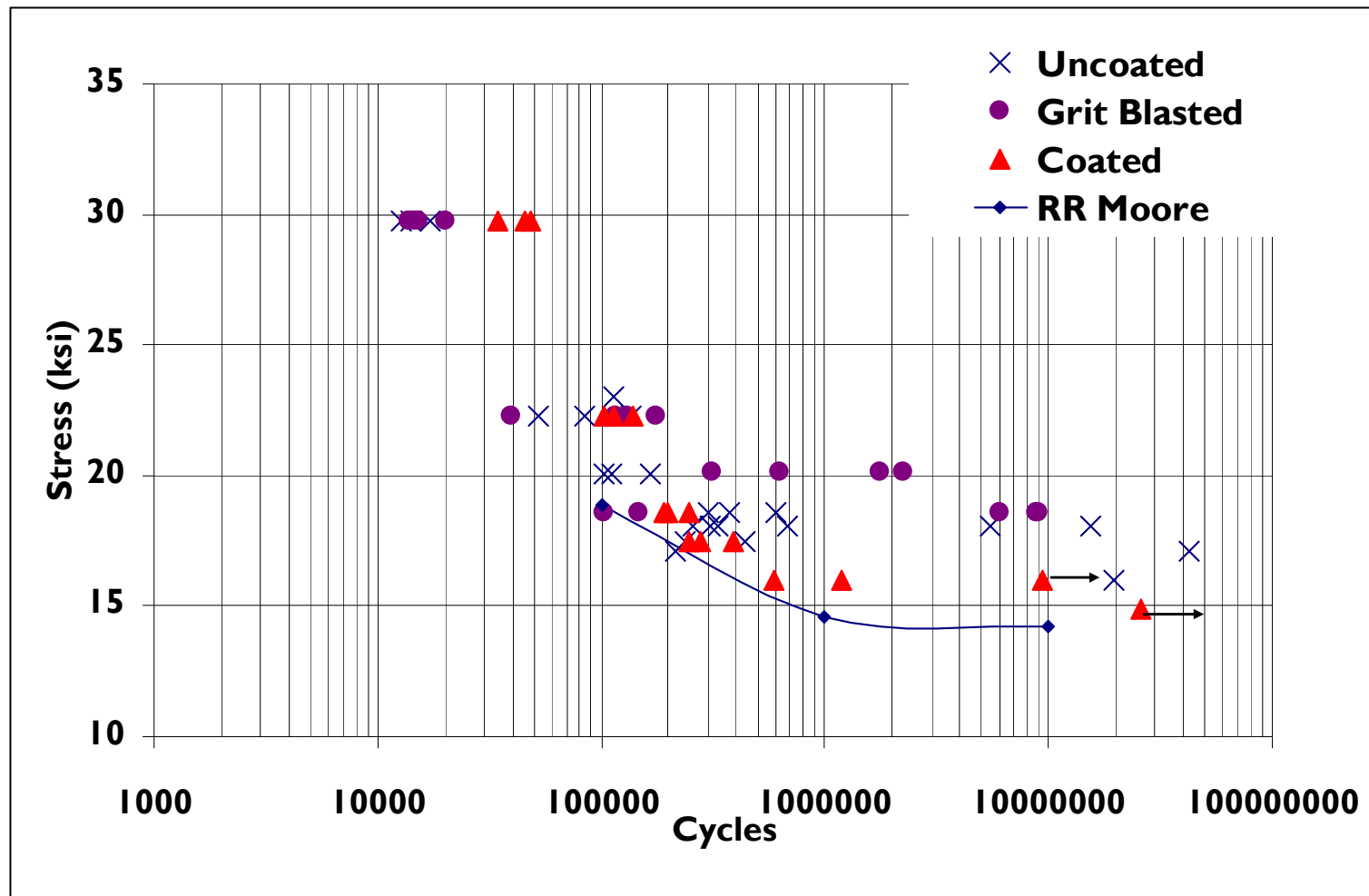
- AZ91C-T6 and EV31-T6 failed with a relatively clean break at coating the interface
- 7 out of 12 ZE41A-T5 samples failed within the Mg





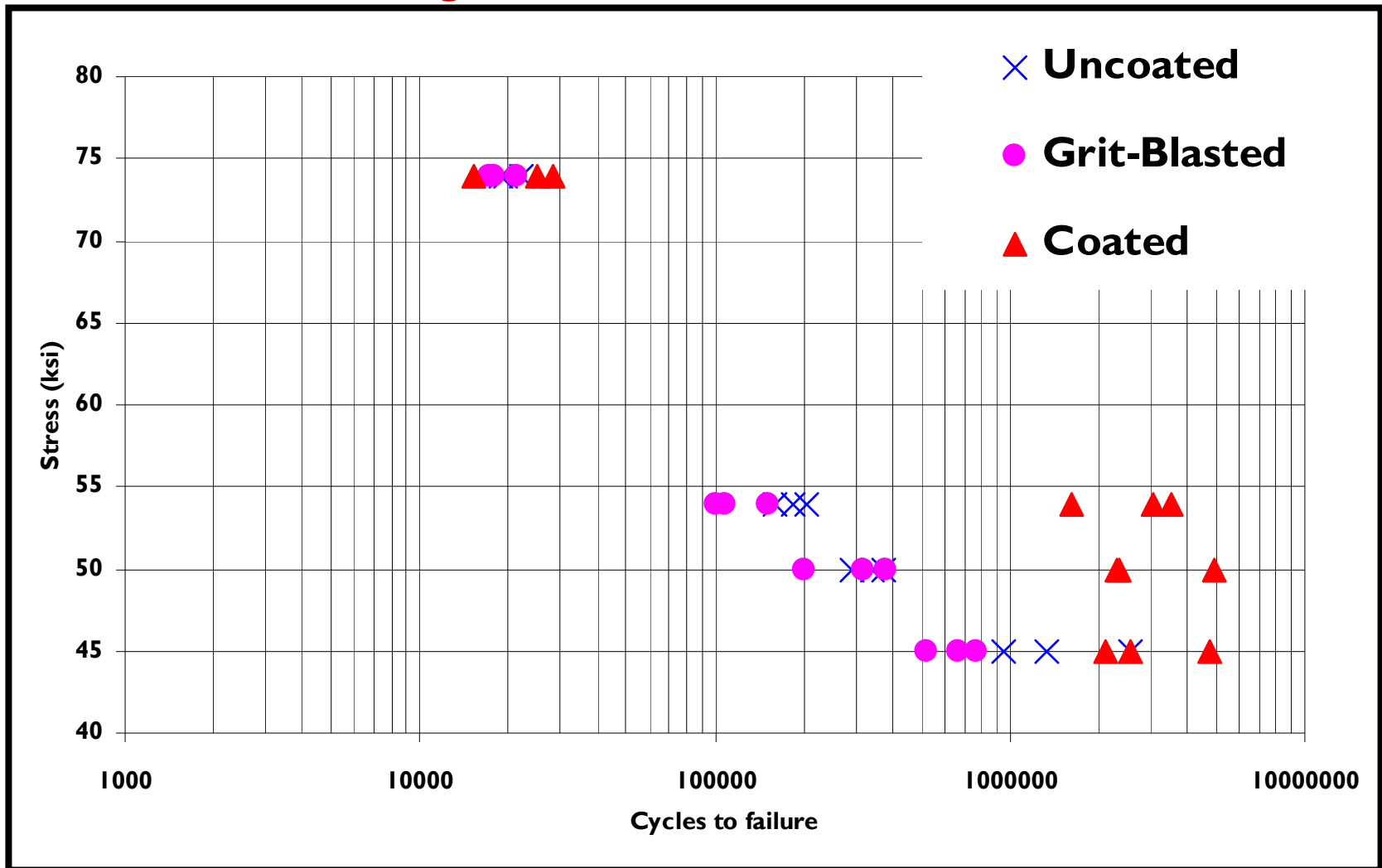


## *Fatigue Results – ZE41A-T5*

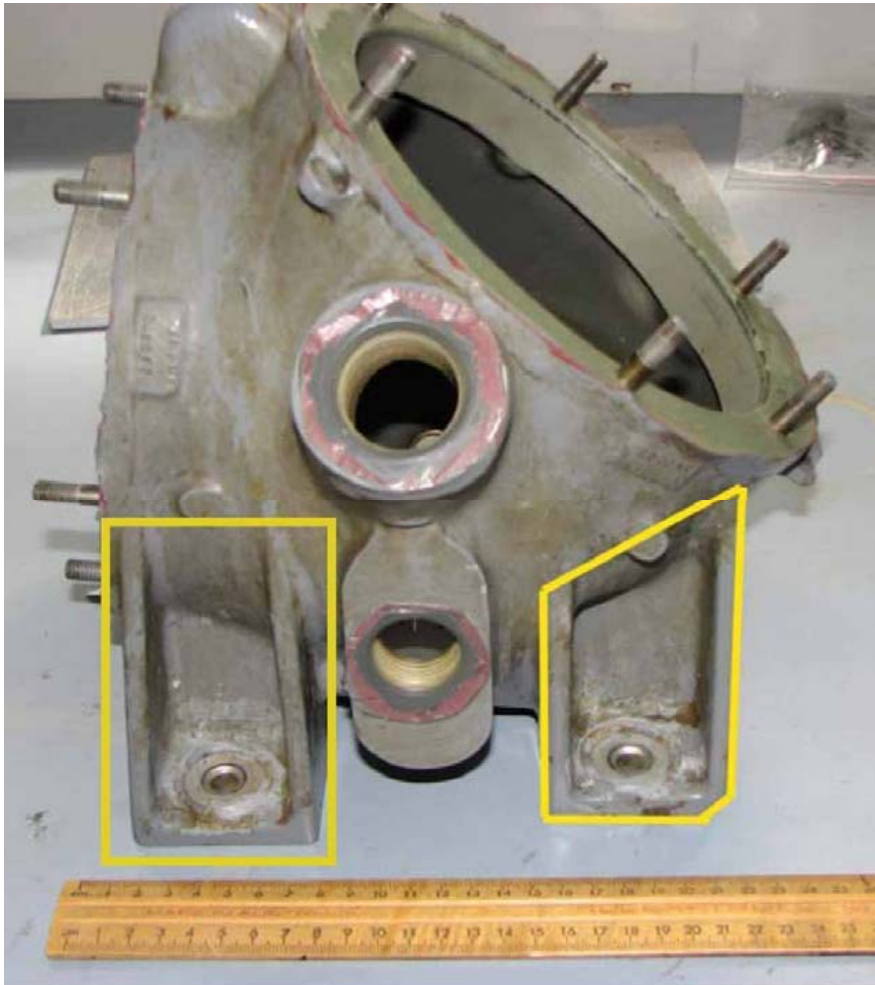


Source – Australian Defense Science & Technology Organization

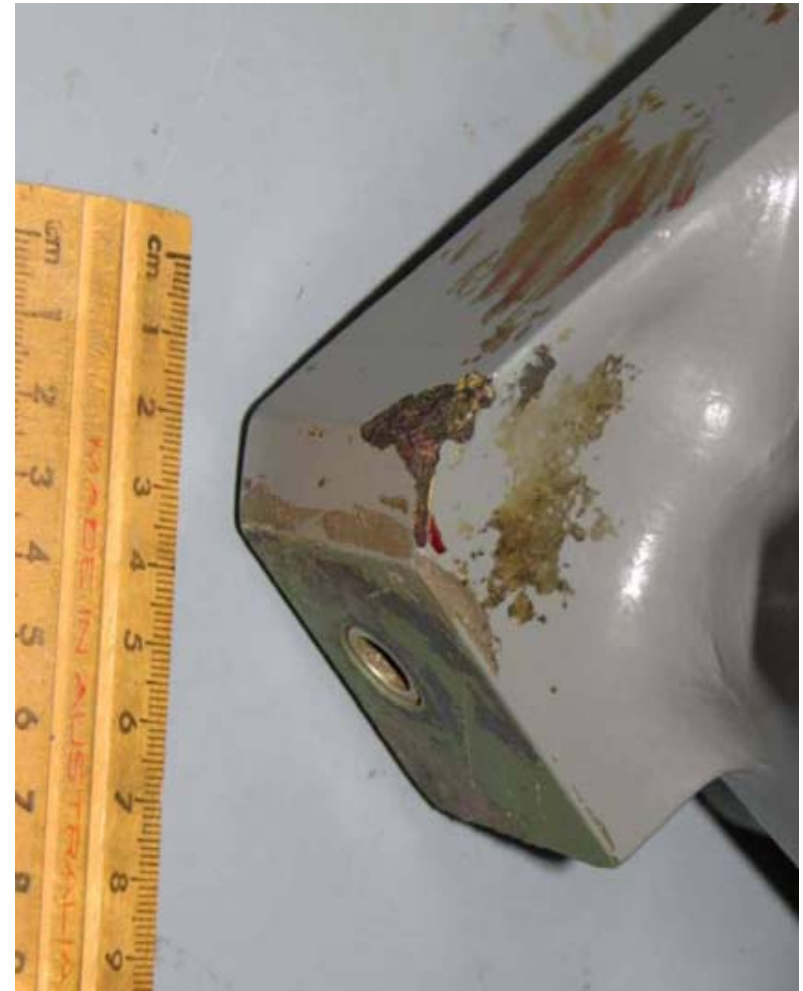
## *Fatigue Results – AA7075-T651*



Source – Australian Defense Science & Technology Organization



*Interior section of Intermediate Gearbox (IGB)*



*Exterior corroded area on one of the as-received IGB pads*



## *Interior section of IGB pads coated with CP-aluminum*

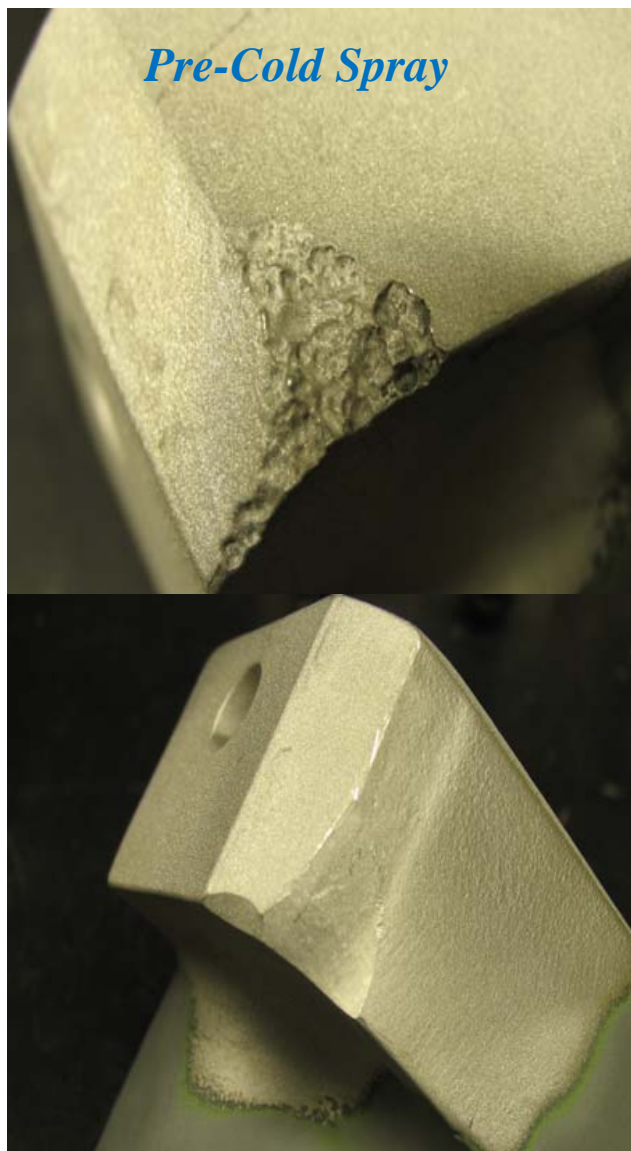


*Pre-Cold Spray*

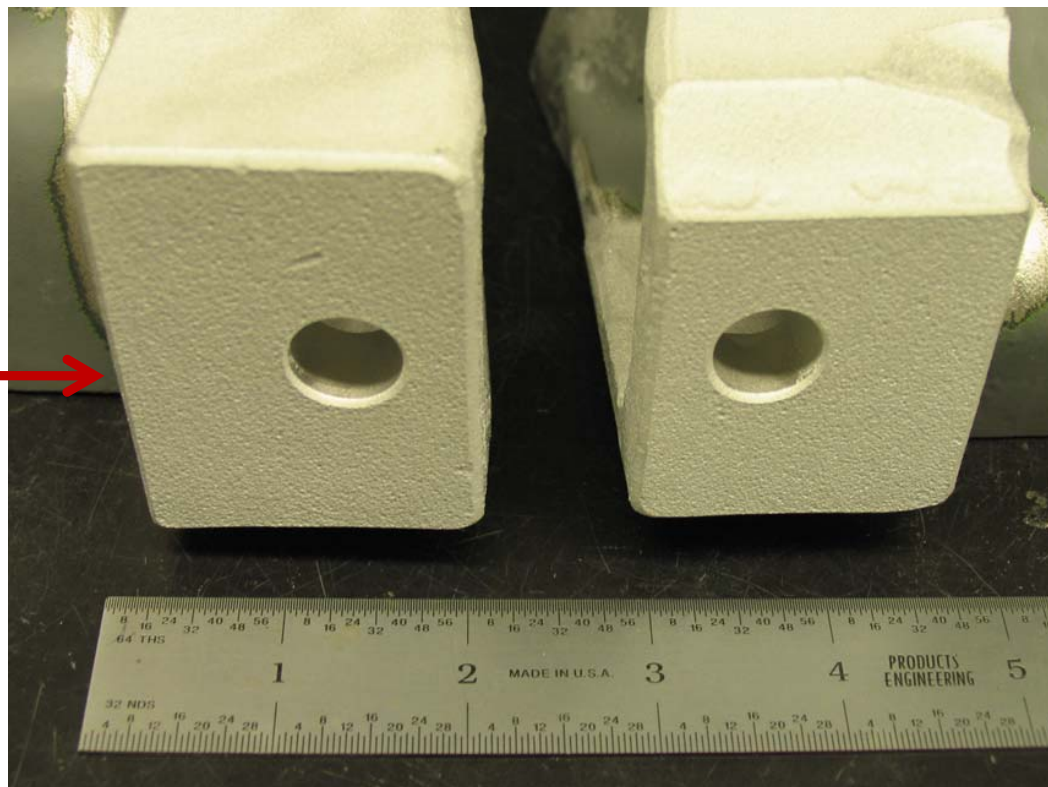


*CP Al Cold Spray*

*Pre-Cold Spray*

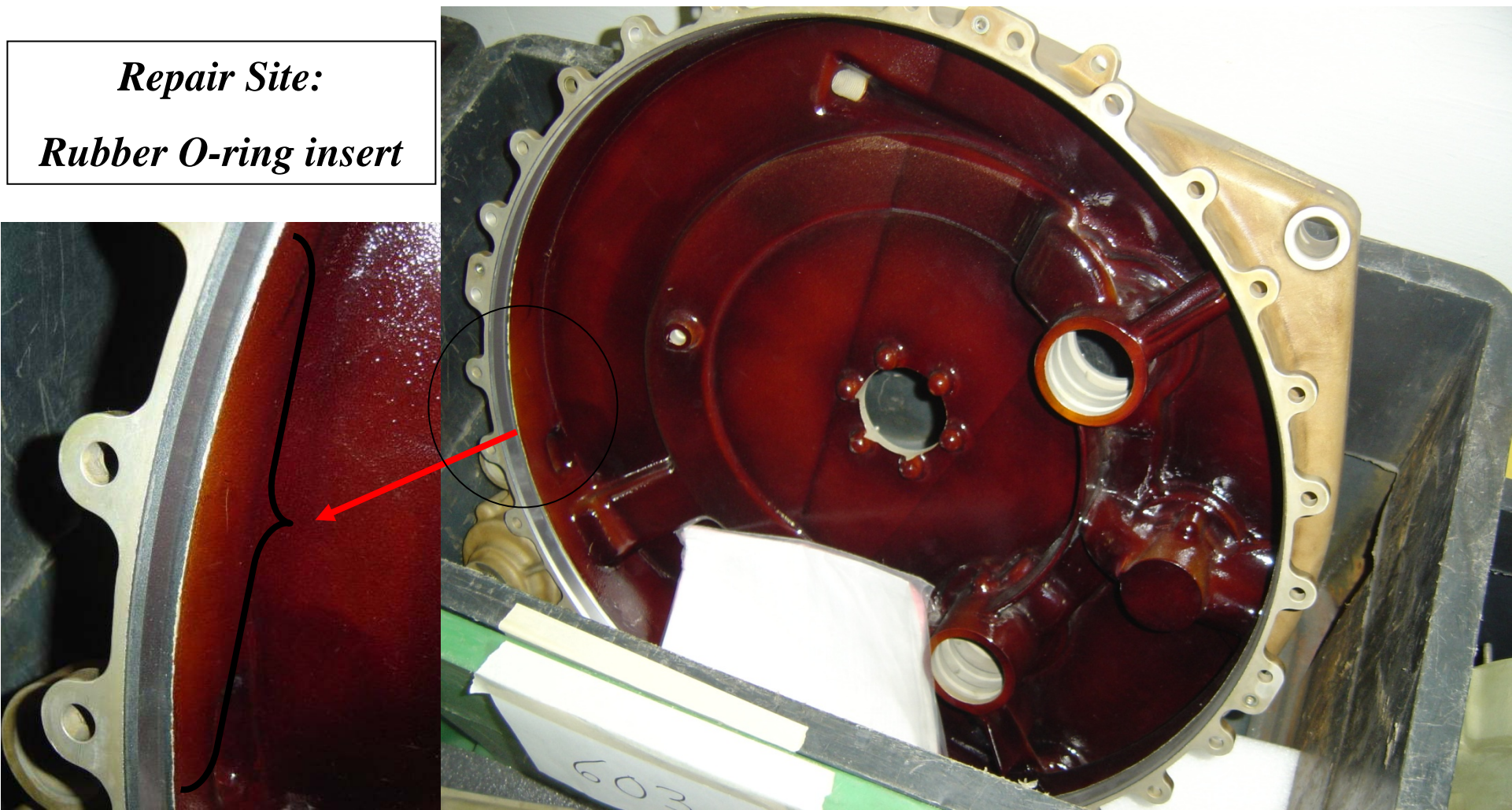


*CP Al Cold Spray*

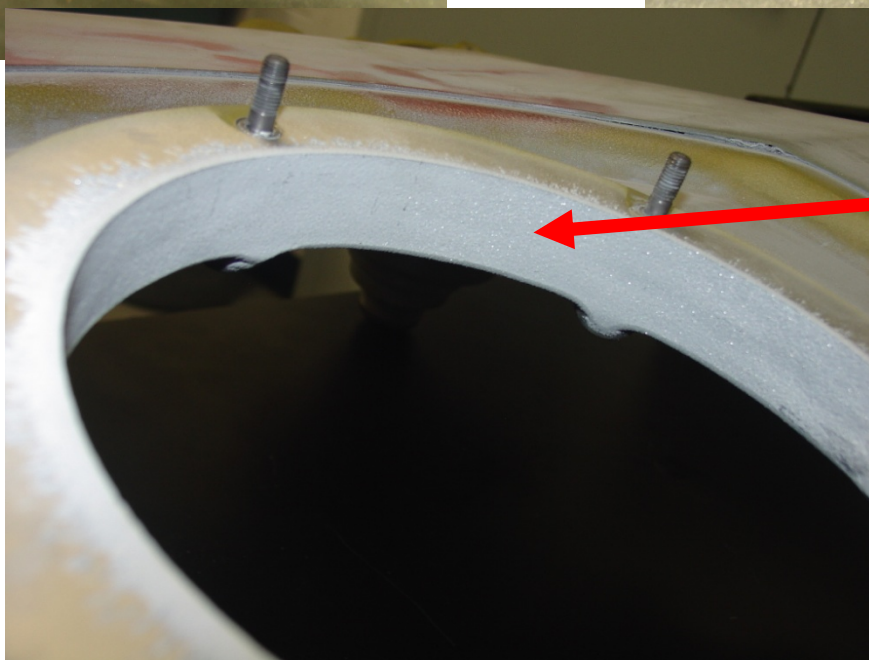
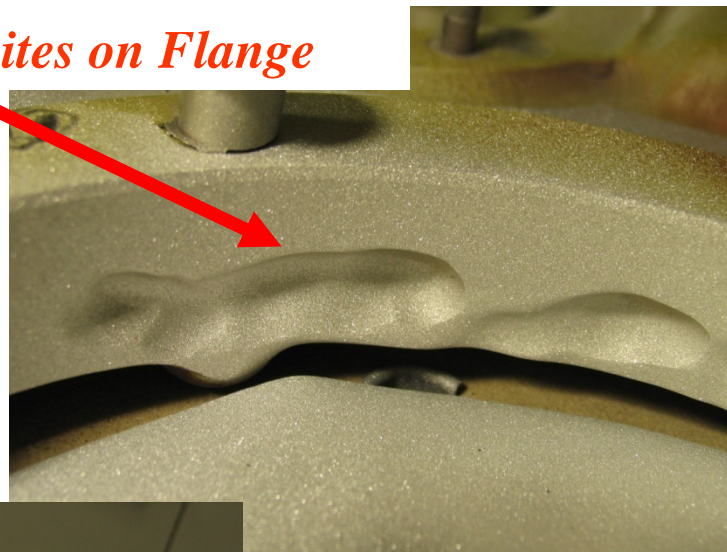
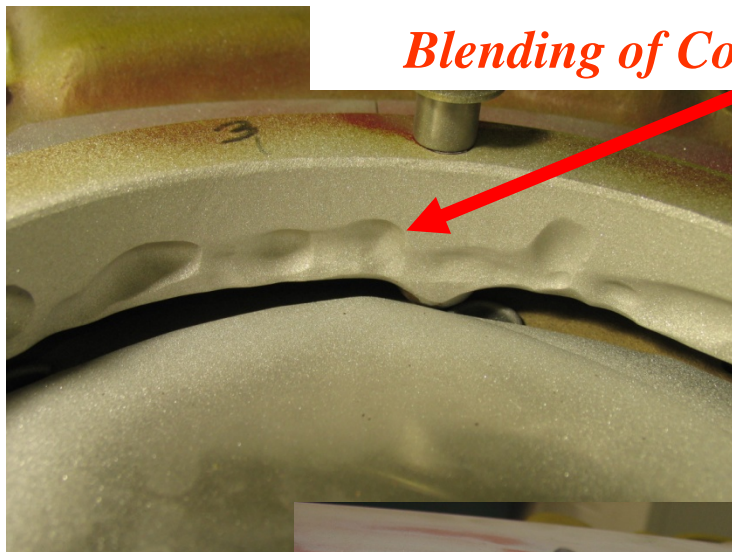




*Repair Site:*  
*Rubber O-ring insert*



*Blending of Corroded Sites on Flange*



*Cold Spray Repair of  
Inside Diameter of  
Flange*





# UH-60 Sump Assembly Main Module -Main Gearbox Repair

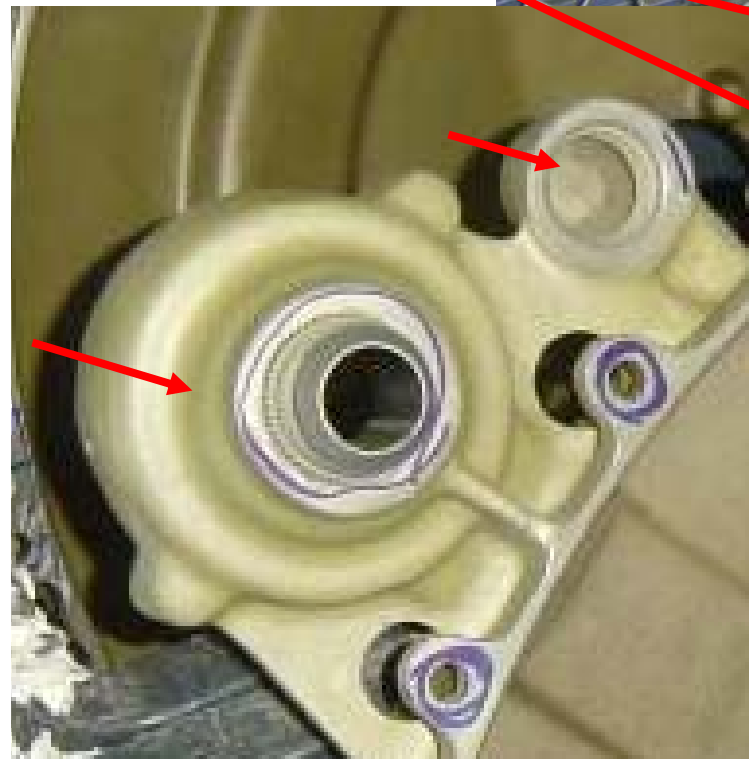
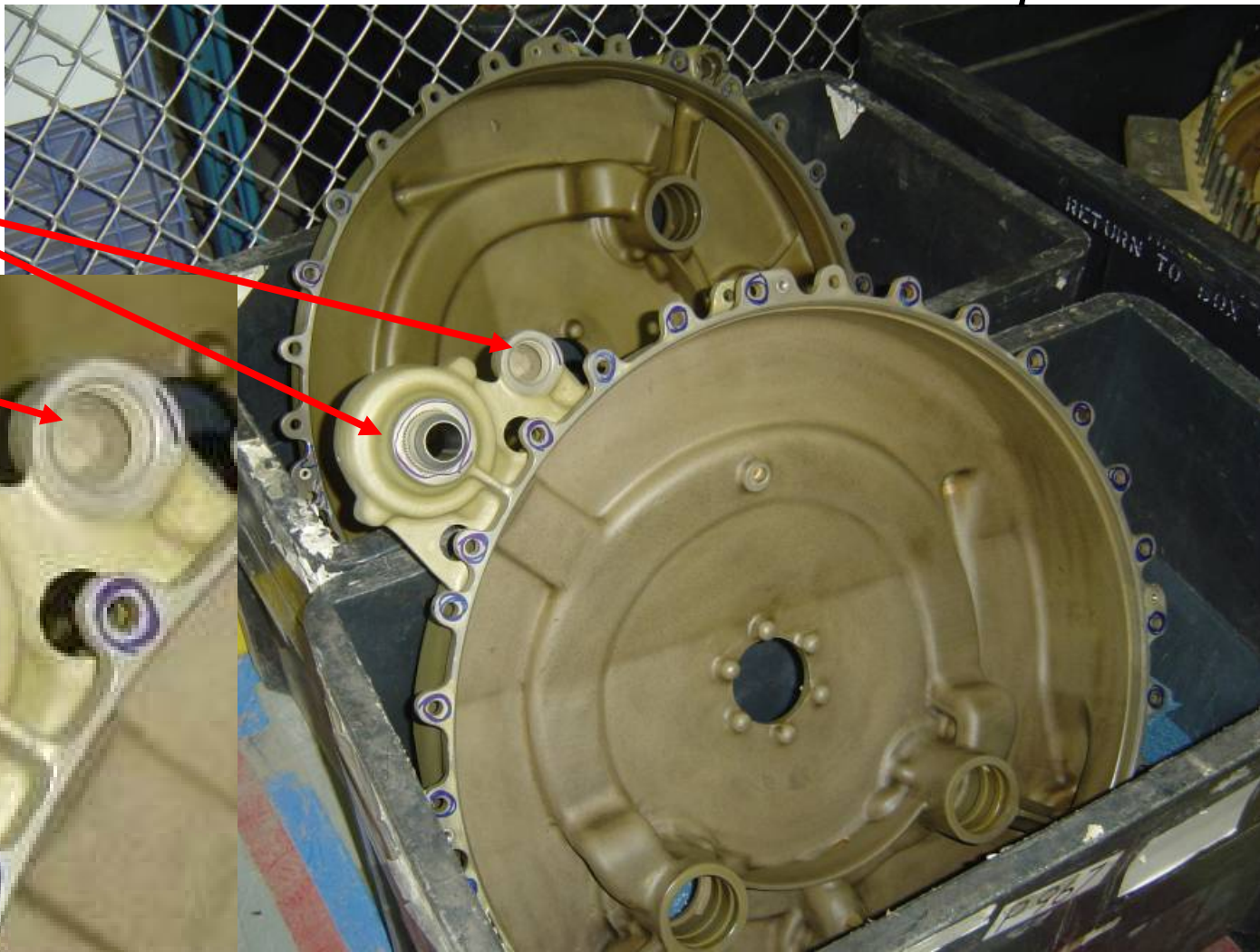


*Repair Site:*

*Filter Bowl Mount*

*Cavities collect water*

*UH-60 Sump Assembly Main Module  
-Main Gearbox Repair*



## Cold Spray offers a cost effective and environmentally friendly method for repair and corrosion protection of Mg Components

### ➤ Hardness

ZE41A Magnesium alloy = 68 Vickers

Cold Spray CP-Al = 63 Vickers

6061=105 Vickers

### ➤ Bond Strength

>6061 has >10,000 psi on ZE41, AZ91, and EV31 (CGT)

>6061 surpassed 15,000 PSI for Triple Lug Shear

>CP-Al/HP-Al has >=10,000 psi on ZE41 and AZ91 (K-Tech and CGT)

### ➤ RCB Fatigue Strength

Minimal effect on both 7075-T6 and ZE41A Magnesium Alloy

### ➤ Salt Fog Corrosion

>4000 hrs on CGT (on going) and 6000+ hrs for K-Tech